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EFFECT OF OXYGENATED PORE-WATER ON ANKUR IRON ORE, NE SUDAN

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ABSTRACT

The present work deals with the mineral alterations that have taken place in Ankur iron ore and its associated country rocks, by means of oxygenated pore-water. The investigations were carried out by the electron-scanning microscope. The alteration products involve; goethite, hematite, hydromuscovite, chlorite, kaolinite, dolomite, gypsum and amorphous silica. Some of the alteration products exist in small concentrations that can not be detected by the X-ray diffraction or the chemical analyses of the bulk samples.

The alteration mechanisms are believed to be direct response to the stability framework of the primary mineralogical composition and the nature of the pore-water as well.

INTRODUCTION

The Ankur area is located between latitudes 21°15′ and 21°55′ N, and longitudes 36°00′ and 36°25′ E, within the Sofaya (Salala) village, in the northeast of Sudan. The area lies about 320 km northwest of Port Sudan and about 90 km west of Abu Imama harbour, on the Red Sea coast *(Fig. 1)*.

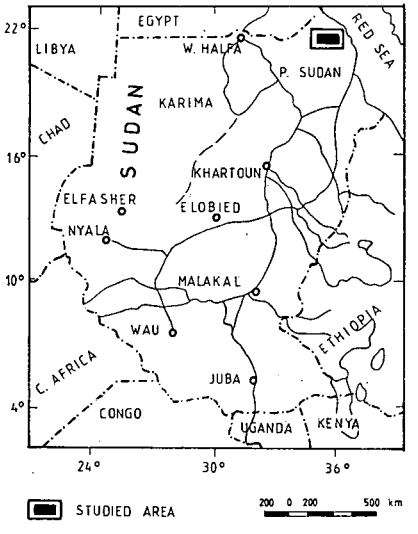

Fig. 1. Location map

The iron ore of Ankur area is characterised by being massive, compact, finely crystalline with steel metallic luster and is intruded into basic schistose rocks. The studied iron ore rank is estimated to be about four million tons of 50—60% Fe.

Two categories of the iron ore can easily be distinguished, namely; massive and disseminated ores. The calculated normative composition is determined to cover a wide variety of minerals, including; quartz, orthoclase, albite, anorthite, corundum, acmite, wollastonite, enstatite, ferrosilite, magnetite, hematite, ilmenite, apatite and pyrite. The V module of the studied magnetites reflects a metamorphic origin of the deposits. V^{3+} occurs in the magnetite lattices substituting for Fe^{3+}, while Cr, Cu, Co, Ni, Zn and Rb are most probably accommodated in the structures of the different aluminosilicates [OSMAN, 1980).

EXPERIMENTAL

Representative samples of the different grades of the ore, as well as the country rocks were examined by the electron-scanning microscope (ESM). The used instrument is of the JSM—35, JEOL type, and it is accommodated with a computerised X-ray fluorescence unit to facilitate a rapid and precise chemical analysis of the examined field.

The samples were prepared for the ESM examination by mounting a fresh piece of rock sample on an aluminium holder. The exposed surface was coated by a thin filament of gold and palladium.

DISCUSSION

The present article is concerned with the mineralogical modifications that have taken place in the studied ores and their country rocks, via interaction with oxygenated pore-waters. The studied area, being tropical, is affected by periodical and aperiodical rainfall, and waters of other sources, which may percolate through dissection and fracture planes in the deposits. Such water may cause slight or extensive break down of minerals, depending upon their stability framework as well as the nature of the

Fig. 2. SEM photomicrograph showing iron-rich flakes on surface of oxidized pyrite

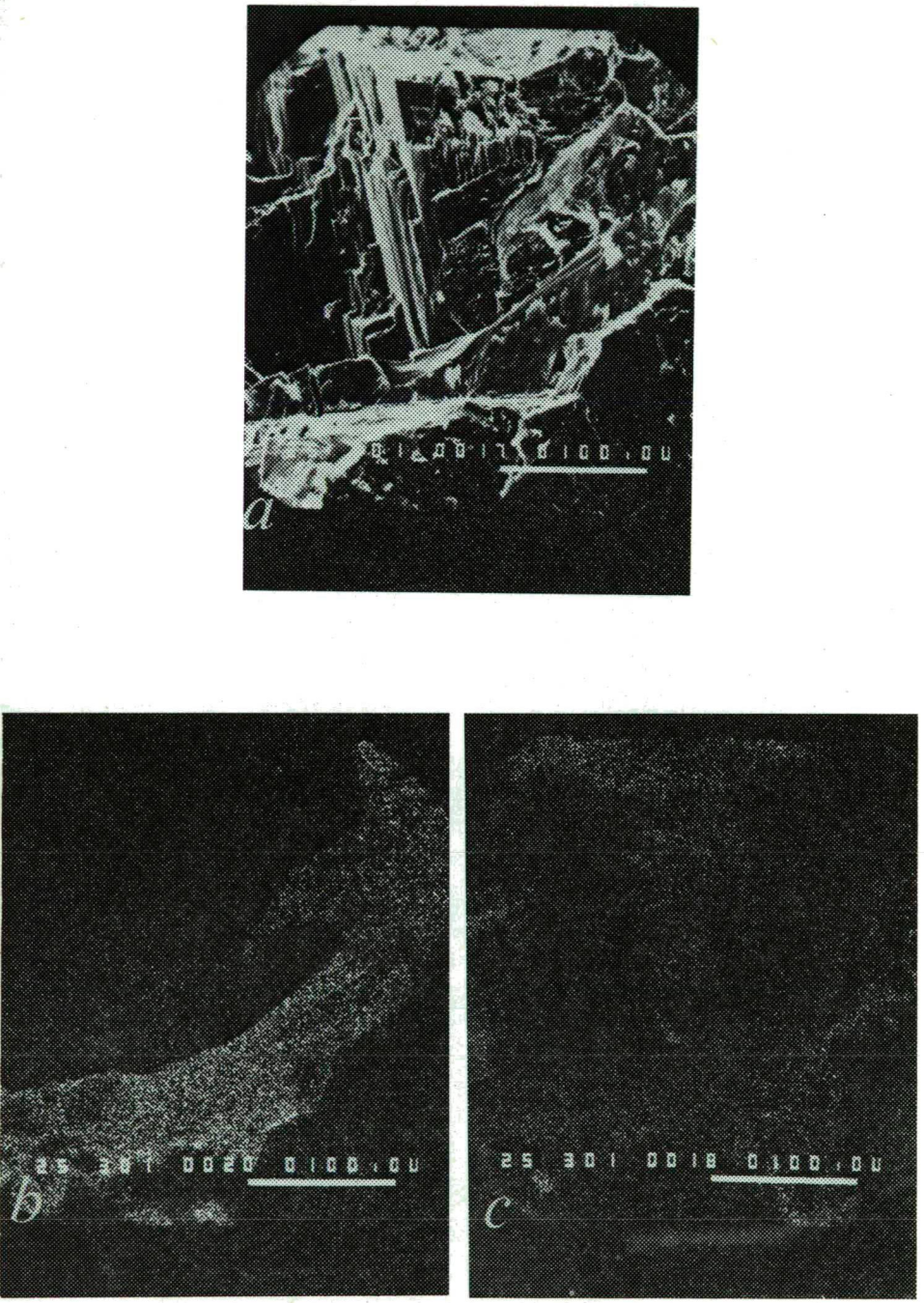

Fig. 3. a) SEM photomicrograph showing aggregates of biotite surrounded by pyrite; notice the development of the iron rich flakes on the oxidized pyrite; b) and c) distribution patterns of Fe and Si, respectively

acting pore-water. The process leads, decisively to certain dispersion of elements which may facilitate possibilities of geochemical prospection.

The electron-scanning microscope (ESM) investigations proved that new minerals have been formed on the expense of others, by the action of the oxygenated pore-water. Some of the alteration products (e.g., dolomite and goethite) do exist in minor amounts that can not be detected by the petrographic microscope, X-ray diffraction or chemical analysis.

Pyrite seems to be the most affected by the oxygenated pore-water. The beginning of its break down appears as etching and pitting on the crystal faces. Predominant flakes, remarkably rich in iron and poor in sulfur, oftenly grow on the surfaces of the oxidized pyrite *(Figs 2* and *3)*. The oxidized chalcopyrite possesses thin coats of almost pure iron *(Fig. 4)*. This is principally because sulfur is readily mobile compar-

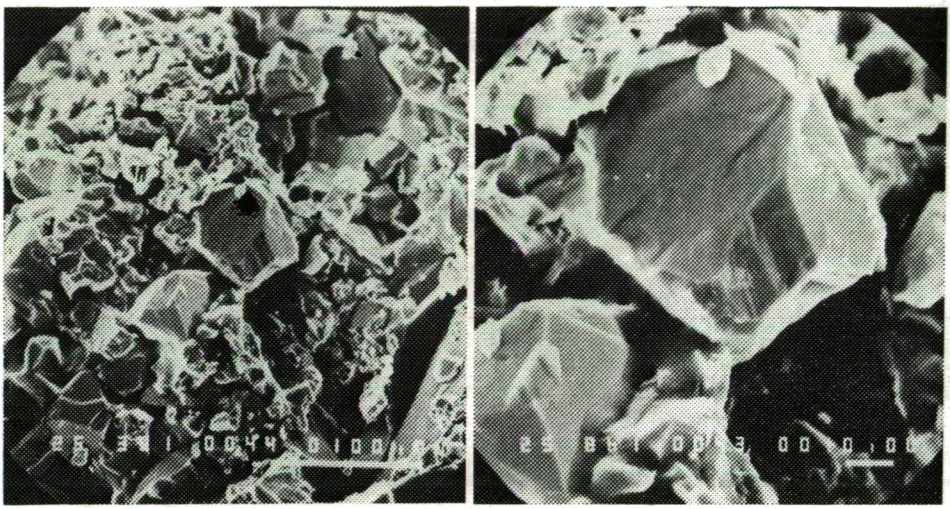

Fig. 4. SEM photomicrographs showing aggregates of chalcopyrite affected by diagenetic solutions; the same field by different magnification

ed to iron. The resultant sulfates may, therefore, move longer to form diagenetic sulfate minerals (e.g., gypsum). The field observations and the petrographic examinations indicated the presence of secondary gypsum as fracture and cavity filling [OSMAN, 1980].

The break down of pyrite by the oxygenated pore-water, has been formalized by KRAUSKOPF [1967], as follows:

$$2FeS_2 + 15/2\ O_2 + 4H_2O \rightarrow Fe_2O_3 + 4SO_4^{2-} + 8H^+$$

$$SO_4^{2-} + 2H_2O + CaCO_3 \rightarrow CaSO_4 \cdot 2H_2O + CO_3^{2-}$$

The reaction between the oxygenated pore-water and magnetite is rather significant. It is partly or entirely oxidized into hematite and/or goethite, which are commonly reprecipitated in situ. The produced hematite is poorly crystalline and keeps, sometimes, a colloidal aspect *(Fig. 5)*. Goethite exhibits a colloform texture, and it fills many pore-spaces and factures *(Fig. 6)*. Sometimes, goethite is reprecipitated on the surfaces of the oxidized magnetite crystals *(Fig. 7)*.

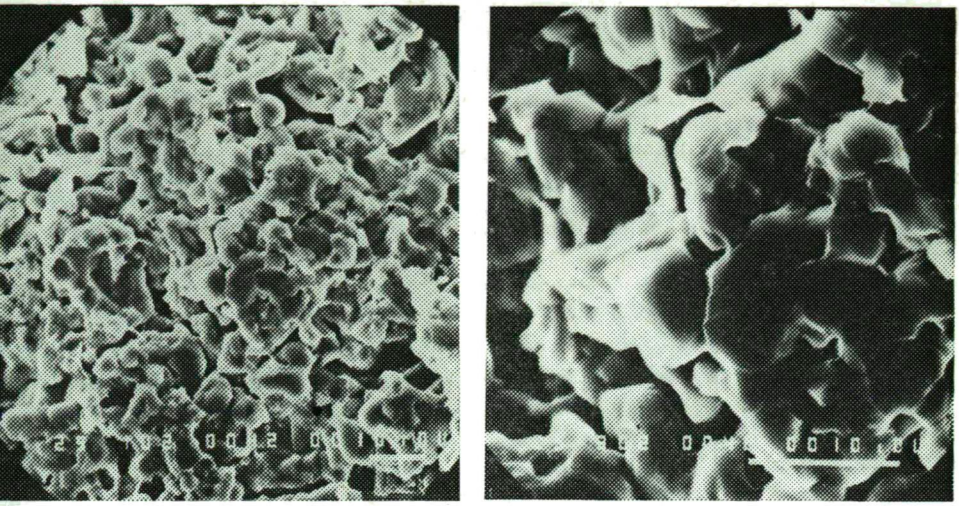

Fig. 5. SEM photomicrographs showing the precipitation of diagenetic hematite. Two different magnifications

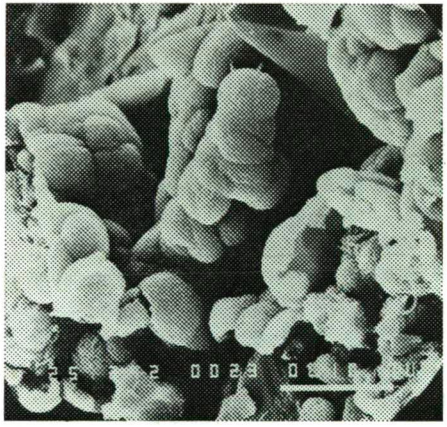

Fig. 6. SEM photomicrographs showing the precipitation of colloidal goethite on euhedral quartz crystals

Limited break down of amphiboles, micas and felspars has frequently been encountered in the studies ores and their country rocks. The alteration products are commonly hydromuscovites, chlorite, kaolinite, amorphous silica and poorly crystalline alumino-silicates. The later is a rare constituent and it occurs as pore-filling *(Fig. 8)*.

The break down of biotite starts oftenly along the flakes with partial removal of iron *(Fig. 9)*. Kaolinite and chlorite are main alteration products of the primary alumino-silicates. The alteration mechanisms have been formalized by SOMMER [1978] and NAGTEGAAL [1980], as follows;

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4$$

K-Feldspar Kaolinite

$$2K(Mg, Fe)_3AlSi_3O_{10}(OH)_2 + H_2O + 14H^+ \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+ + 6(Mg^{2+}, Fe^{2+})$$

Biotite — Kaolinite

The formation of kaolinite requires an almost fresh water containing very low K^+/H^+ ratio [READING, 1978]. The released K^+, Mg^{2+} and Fe^{2+}, from the breakdown of biotite and feldspar, can be used for the formation of other diagenetic minerals such as chlorite and dolomite [EL-KAMMAR *et al.*, 1980].

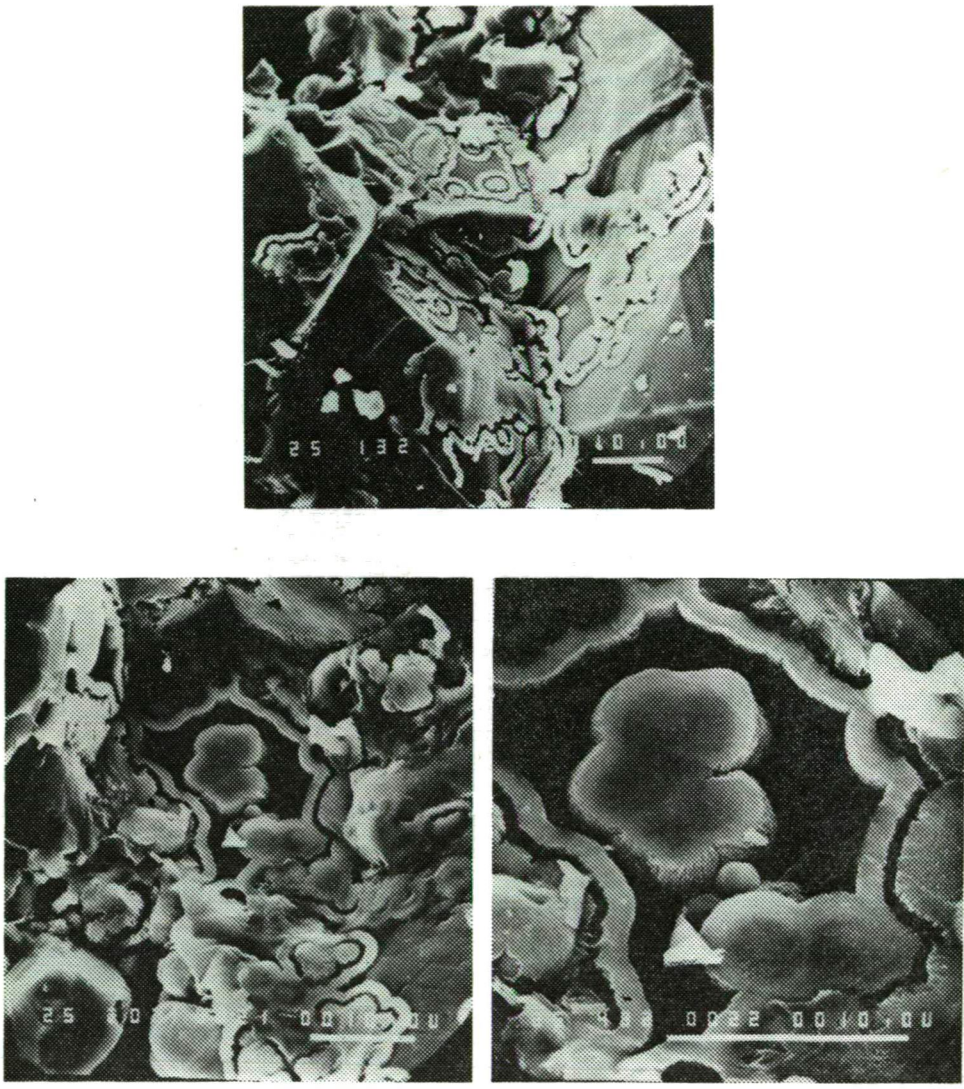

Fig. 7. SEM photomicrographs with different magnifications showing the precipitation of colloidal goethite on the surface of magnetite crystal. The goethite displays clear colloform texture. The crumbled surfaces of the colloidal goethite is due to shrinkage during solidification

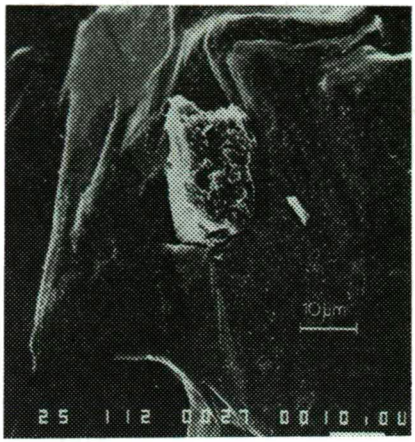

Fig. 8. SEM photomicrograph showing a cavity-filling by poorly crystalline alumino-silicates

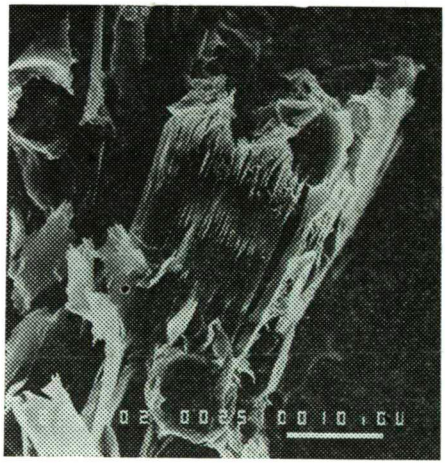

Fig. 9. SEM photomicrograph illustrating the effect of the oxygenated pore-water on biotite crystal

As a result of the late diagenetic activity, xenotipic fine grained dolomite has been observed in some pore spaces *(Fig. 10)*. The precipitation of dolomite requires, according to KINSMAN [1969] and AL-HASHIMY [1976], a slightly acidic medium.

The above study of the electron-scanning microscope proves undoubtedly that a part of the chemical constituents of the studied deposits were redistributed or dispersed due to diagenetic effect of oxygenated pore-water.

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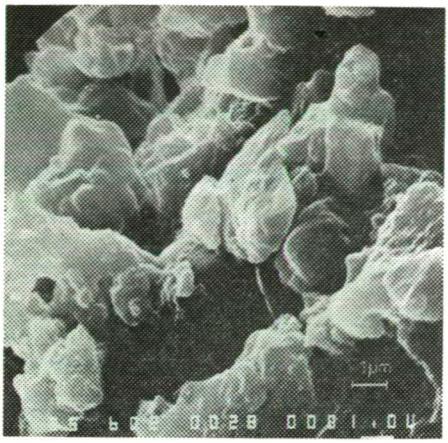

Fig. 10. SEM photomicrograph showing the precipitation of late diagnetic xenotipic dolomites in a pore-space

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